Energy Division

**ROCKY MOUNTAIN AREA PETROLEUM PRODUCT AVAILABILITY
WITH REDUCED PADD IV REFINING CAPACITY**

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Published February 1994
(Research Completed April 1993)

Report Prepared for

Office of Energy Demand Policy
Office of Policy, Planning and Analysis
U.S. Department of Energy

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
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MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

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ACRONYMS AND ABBREVIATIONS

ACCA	Advanced Computing Center of Argenta
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
CAAA	Clean Air Act Amendments of 1990
CG	Conventional gasoline
CI	Conversion index
CO	Carbon monoxide
DOE	Department of Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
F	Fahrenheit
gm/mi	Grams per mile
MBD	Thousand barrels per day
MBSD	Thousand barrels per stream day
mg/mi	Milligrams per mile
mpg	Miles per gallon
MTBE	Methyl tertiary butyl ether
NOX	Nitrogen oxides
NPC	National Petroleum Council
NPRA	National Petroleum Refiners Association
OG	Oxygenated gasoline
ORNL	Oak Ridge National Laboratory

ORNL-RYM	Oak Ridge National Laboratory Refinery Yield Model
PADD	Petroleum Administration for Defense District
ppm	Parts per million
psi	Pounds per square inch, absolute
Reg-Neg	Negotiated rule making
REMS	Refinery Evaluation Modeling System
RFG	Reformulated gasoline
RVP	Reid vapor pressure
SIP	State Implementation Plan
TAME	Tertiary amyl methyl ether
TAP	Toxic air pollutant
TBA	Tertiary butyl alcohol
T50	The temperature at which 50 percent of a fuel is evaporated in ASTM test D86-67: Distillation of Petroleum Products
T90	The temperature at which 90 percent of a fuel is evaporated in ASTM test D86-67: Distillation of Petroleum Products
VOC	Volatile organic compound
vol	Volume
WSEO	Washington State Energy Office
wt	Weight

ACKNOWLEDGEMENTS

Support and technical guidance for analysis of Rocky Mountain area petroleum product availability with reduced PADD IV refining capacity have been provided by Barry McNutt and Ben Massell of the Office of Energy Demand Policy of the Department of Energy (DOE) and by Elizabeth Campbell of the Office of Oil and Gas Policy of DOE.

Insights on petroleum markets and refinery trends have been provided by the Product Quality Task Group of the National Petroleum Council Committee on Refining; by the U.S. Oil & Refining Company; Tesoro Petroleum Corporation; the East-West Center Resource Systems Institute; Chevron U.S.A., Inc.; Pacific Resources, Inc.; the Amerada Hess Corporation; the Sun Company; Ashland Petroleum Company; Exxon Company, U.S.A.; Conoco, Inc.; Coastal Corporation; and the American Petroleum Institute.

Technical guidance, data resources, and access to forecasting models have been furnished by the DOE Energy Information Administration. EnSys Energy & Systems, Inc., and Turner, Mason & Company have assisted in modification of the refinery models.

Throughout the development and application of the Oak Ridge National Laboratory Refinery Yield Model used in these studies, support and guidance have also been received from the Navy Energy & Natural Resources Office, the Naval Air Propulsion Center, and the David Taylor Naval Ship Research and Development Center.

Suzy Deutsch, Robert Gibson, and Angela Gibson, all of the University of Tennessee, and Maggie Bruer of Oak Ridge National Laboratory provided technical and editorial assistance in the production of this report. The valuable contributions of these organizations and individuals are greatly appreciated.

ABSTRACT

Studies of Rocky Mountain area petroleum product availability with reduced refining capacity in Petroleum Administration for Defense District IV (PADD IV, part of the Rocky Mountain area) have been performed with the Oak Ridge National Laboratory Refinery Yield Model, a linear program which has been updated to blend gasolines to satisfy constraints on emissions of nitrogen oxides and winter toxic air pollutants. The studies do not predict refinery closures in PADD IV. Rather, the reduced refining capacities provide an analytical framework for probing the flexibility of petroleum refining and distribution for winter demand conditions in the year 2000. Industry analysts have estimated that, for worst case scenarios, 20 to 35 percent of PADD IV refining capacity could be shut-down as a result of clean air and energy tax legislation. Given these industry projections, the study scenarios provide the following conclusions:

The Rocky Mountain area petroleum system would have the capability to satisfy winter product demand with PADD IV refinery capacity shut-downs in the middle of the range of industry projections, but not in the high end of the range of projections.

PADD IV crude oil production can be maintained by re-routing crude released from PADD IV refinery demands to satisfy increased crude oil demands in PADDs II (Midwest), III (Gulf Coast), and Washington.

Clean Air Act product quality regulations generally do not increase the difficulty of satisfying emissions reduction constraints in the scenarios.

ROCKY MOUNTAIN AREA PETROLEUM PRODUCT AVAILABILITY WITH REDUCED PADD IV REFINING CAPACITY

EXECUTIVE SUMMARY

Among the issues of concern to DOE is the future availability of petroleum products in areas supplied primarily by smaller petroleum refineries. Industry analysts have estimated that as much as 13 percent of U.S. refining could be lost because small refiners may choose to close rather than make investments to reduce refinery pollutant emissions and to produce fuels which comply with environmental regulations.

The Petroleum Administration for Defense District IV (PADD IV, part of the Rocky Mountain area) has, on average, the smallest and least complex refineries of any U.S. region. Faced with investments required to comply with environmental regulations, small refineries representing 17 percent of crude distillation capacity in PADD IV have recently considered sale or shut-down of operations. Given industry estimates of the potential loss of small refineries, and the recent refinery sales and closure activity in PADD IV, Oak Ridge National Laboratory (ORNL) has performed modeling and analysis of the impacts of reduced refining capacities in PADD IV.

The scenario season is winter of the year 2000, selected because of DOE's concerns about adequate supplies of essential heating oils and diesel fuels. Typically, winter demand for PADD IV products is low, with low pipeline utilization, and greater flexibility to obtain product from other regions: conditions that are conducive to depressed utilization of PADD IV refineries, and perhaps to depressed economic performance. Furthermore, through displacement of conventional gasoline blendstocks, oxygenates required by the Clean Air Act Amendments of 1990 (CAAA) can reduce utilization of gasoline production processes within the refinery. Compared to summer gasoline, a far greater proportion of winter gasoline in PADD IV will be affected by the oxygenated and reformulated gasoline requirements of the CAAA.

Studies of Rocky Mountain area petroleum product availability have been performed with the ORNL Refinery Yield Model (ORNL-RYM), a linear program which has been updated to blend gasolines to satisfy constraints on emissions of nitrogen oxides and winter toxic air pollutants. Non-linear emissions models have been represented in ORNL-RYM by assuming that an emission value can be represented as a base emission value plus small linear emissions changes due to small changes in gasoline properties.

The Rocky Mountain area consists of (1) domestic areas which supply crude oil and refined products to PADD IV and (2) domestic areas which are supplied crude oil and refined products by PADD IV. The Rocky Mountain area petroleum system includes the following activities:

PADD IV refineries manufacture products for consumers in PADDs II (Midwest) and IV and in eastern Washington state.

PADD IV produces crude oils for refineries in PADDs II, III (Gulf Coast), and IV.

PADD II refineries manufacture products for consumers in PADD IV.

PADD III refineries manufacture products for consumers in PADD IV.

Washington refineries can manufacture products for eastern Washington consumers, who are normally supplied by PADD IV refineries.

The studies do not predict refinery closures. The reduced refining capacities for PADD IV simply provide an analysis framework for probing the flexibility of petroleum refining and distribution in the Rocky Mountain area. Reduced refining capacities result in increased product costs. If costs are passed to the consumer, demand may fall and other product suppliers may enter the market over a period of time. However, these studies are concerned with very-short-term imbalances, and product cost increases are estimated without consideration of market adjustments.

Three scenarios are studied. Refineries are included in a scenario, based upon refinery complexity as measured by the conversion index ($CI = \frac{\sum \text{conversion unit capacities}}{\text{capacity}} \times 100$, where conversion units include catalytic cracking units, hydrocracking units, and coking units):

Scenario 1: Maximize Pipeline Utilization: A twelve refinery PADD IV system, with individual refinery conversion indices (CIs) greater than 32, is identified in which product demand can be satisfied by using slack in the pipeline system and in refineries of other regions. Although production costs change very little in other regions, *production (marginal) costs increase in PADD IV by 10-11 cents per gallon of product in this scenario.*

Scenario 2: Maximize Product from Washington Refineries: An eleven refinery PADD IV system, with individual refinery CIs of at least 34, is identified in which it is necessary to maximize the deliveries of product from Washington refineries to consumers in eastern Washington. In this scenario, *production costs in PADD IV increase by about 6-7 cents per gallon of product.* Including transportation cost increases, the total cost increase for product refined in Washington and delivered to Spokane area consumers is about 5-6 cents per gallon.

Scenario 3: Minimum Required Refining Capacity: A nine refinery PADD IV system, with individual refinery CIs of at least 38, is identified as a *system of minimum required refining capacity.* Elimination of one additional refinery would result in a system which could not satisfy product demand because of insufficient crude processing capacity.

For the scenario with the greatest change in regional demands for crude oils, the studies show that PADD IV crude oil production can be maintained. Increased crude demands in PADDs II, III, and Washington can be satisfied by re-routing crude released from PADD IV refinery demands. The re-routing scheme causes only minor product cost increases in Washington.

Industry analysts have estimated that, for worst case scenarios, 104 to 185 MBD (20 to 35 percent) of PADD IV refining capacity could be shut-down as a result of clean air and energy tax legislation. Given these industry projections, the scenario study results support the following conclusions:

The Rocky Mountain area petroleum system would have the capability to satisfy winter product demand, with PADD IV refinery capacity shut-downs in the middle of the range of industry projections.

The Rocky Mountain area petroleum system would not have the capability to satisfy winter product demand, with PADD IV refinery capacity shut-downs in the high end of the range of industry projections

PADD IV crude oil production can be maintained by re-routing crude released from PADD IV refinery demands to satisfy increased crude oil demands in PADDs II, III, and Washington. This conclusion holds for all scenarios.

CAAA product quality regulations generally do not increase the difficulty of satisfying emissions reduction constraints in the scenarios.

1. THE SMALL REFINERY PROBLEM

Among the issues of concern to DOE is the future availability of petroleum products in areas supplied primarily by smaller petroleum refineries. Industry analysts have estimated that as much as 13 percent of U.S. refining could be lost because small refiners may choose to close rather than make investments to reduce refinery pollutant emissions and to produce fuels which comply with environmental regulations.¹

As shown in Table 1.1, Petroleum Administration for Defense District IV (PADD IV, with PADDs defined in Fig. 1.1) has, on average, the smallest and least complex refineries of any U.S. region. In Table 1.1, refinery complexity is measured by the conversion index ($CI = \Sigma \text{ conversion unit capacities} \div \text{crude capacity} \times 100$, where conversion units include catalytic cracking units, hydrocracking units, and coking units²).

Table 1.1. Regional U.S. refinery size and complexity (January 1, 1992)		
Region	Average operating atmospheric crude oil distillation capacity (MBSD)	Complexity (Conversion index)
PADD I (East Coast)	82.6	50
PADD II (Midwest)	92.6	53
PADD III (Gulf Coast)	105.8	57
PADD IV (part of the Rocky Mountain area)	33.0	44
PADD V (West Coast)	70.9	62
Washington state	79.8	45

Faced with investments required to comply with environmental regulations, small refineries representing 17 percent of crude distillation capacity in PADD IV have recently considered sale or shut-down of operations:

The 30 thousand barrel per day (MBD) Amoco refinery in Casper, Wyoming, which has been closed.

The 25 MBD Phillips refinery in Woods Cross, Utah, which Phillips unsuccessfully tried to sell.¹

The 40 MBD Amoco refinery in Salt Lake City, which Amoco unsuccessfully tried to sell.³

Fig. 1.1
Petroleum Administration for Defense Districts

Refinery shut-downs in PADD IV could affect petroleum markets in the larger Rocky Mountain area. The Rocky Mountain area consists of (1) domestic areas which supply crude oil and refined products to PADD IV and (2) domestic areas which are supplied crude oil and refined products by PADD IV. The Rocky Mountain area petroleum system includes crude oil and product supply activities in PADDs II, III, IV, and Washington state. PADD IV petroleum exchanges in the Rocky Mountain area in 1991 are shown in Table 1.2.

Table 1.2. PADD IV petroleum exchanges in the Rocky Mountain area in 1991 (MBD) ⁴			
PADD IV to:	Crude	Gasoline	Other Products
PADDs II and III	129	-30	-7
Washington state	0	31	16

Given industry estimates of the potential loss of small refineries, and the recent refinery sales and closure activity in PADD IV, Oak Ridge National Laboratory (ORNL) has performed modeling and analysis of the impacts of various PADD IV refining capacity scenarios. Key issues addressed in the analysis and discussed in this report include:

Petroleum product cost and availability implications for the Rocky Mountain area.

Problems and costs associated with re-routing crude oils and products to alternate destinations.

The scenario season is winter of the year 2000, selected because of DOE's concerns about adequate supplies of essential heating and diesel fuels. Typically, winter demand for PADD IV products is low, with low pipeline utilization, and greater flexibility to obtain product from other regions: conditions that are conducive to depressed utilization of PADD IV refineries, and perhaps to depressed economic performance. For example, in 1991, PADD IV refinery atmospheric crude oil distillation capacity utilization was 74 percent in January, compared to 89 percent in July.⁴

Furthermore, through displacement of conventional gasoline blendstocks, oxygenates required by the Clean Air Act Amendments of 1990 (CAAA) can reduce utilization of gasoline production processes within the refinery. Compared to summer gasoline, a far greater proportion of winter gasoline in PADD IV will be affected by the oxygenated and reformulated gasoline requirements of the CAAA. One projection of the seasonal gasoline balance for PADD IV is shown in Table 1.3.⁵

Table 1.3.
PADD IV seasonal gasoline balance for the year 2000⁵

CG = conventional gasoline

RFG = reformulated gasoline

OG = oxygenated gasoline

	Summer gasoline (MBD)		Winter gasoline (MBD)		
	CG	RFG	CG	RFG	OG
Consumer demand	205	31	96	28	86
PADD IV production	214	31	122	28	79
Transfers to PADD II	15		15		
Transfers from PADDs II and III	35		5		20
Transfers to Washington state	29		16		13

2. THE CLEAN AIR ACT AMENDMENTS OF 1990

The CAAA will have far-reaching effects on the refining industry because, in addition to installing maximum achievable technologies to control in-plant emissions of numerous compounds, refiners will have to design, permit, and construct new units to produce mandated clean fuels. There are programs in the CAAA for oxygenated gasoline (OG) and for reformulated gasoline (RFG).

The OG program requires that, beginning November 1, 1992, gasoline with a minimum oxygen content of 2.7 weight percent must be sold during winter months in about 40 cities not in compliance with carbon monoxide (CO) standards. RFGs are required by January 1, 1995, in nine areas with extreme or severe ozone pollution problems ("covered ozone nonattainment areas"). About 90 other cities with marginal, moderate, or serious ozone problems may "opt-in" to the RFG program.

The law specifies a formula and emissions performance standards for RFG. *For the winter season*, these standards include:

A minimum oxygen content of 2 weight percent;

A maximum benzene content of 1 volume percent (the 1990 industry average gasoline contained 1.53 volume percent benzene);

No additives with heavy metals;

No increase in nitrogen oxide (NOX) emissions compared to present gasolines;

Beginning in 1995, a reduction in toxic air pollutants (TAPs) such that a 15 percent reduction in TAPs is realized for the entire year, compared to 1990 levels. Beginning in the year 2000, TAP emissions for the entire year are required to be at least 20 percent below 1990 levels. TAPs consist of benzene, 1,3 butadiene, formaldehyde, acetaldehyde, and polycyclic organic matter.

The Environmental Protection Agency (EPA) used the negotiated rule making (Reg-Neg) process to allow parties who would be affected by the CAAA gasoline programs to negotiate an approach to the requirements of Phase I (1995). The CAAA requires a formal fuel certification procedure for demonstrating the emissions performance of a fuel. During the Reg-Neg workshop on fuel certification, the concept of emissions modeling was discussed. Emissions modeling provides a means for predicting the emissions performance of a gasoline, given other physical and chemical properties of the gasoline. On August 16, 1991, an agreement in principle established two emissions models: the Simple Model and the Complex Model.

The Simple Model is a set of equations that predicts emissions of volatile organic compounds (VOCs) and TAPs in terms of a gasoline's Reid vapor pressure (RVP), benzene, oxygen, and aromatics contents. VOCs include all oxygenated and non-oxygenated hydrocarbons except for methane and ethane. VOC control is required during the high ozone season, not during winter.

The Complex Model will be a set of equations that predicts emissions of VOCs, TAPs, and NOX in terms of the values of a larger number of gasoline properties. A preliminary Complex Model published by EPA in October 1992 included RVP, T50, T90, benzene, oxygen, sulfur, aromatics, and olefins contents.⁶

Gasoline producers may use either the Simple Model or the Complex Model or vehicle testing to certify the emissions performance of RFGs manufactured between January 1, 1995, and March 1, 1997. A Simple Model user must also cap the T90, sulfur, and olefins contents of RFG at the average values of his 1990 gasoline. After March 1, 1997, only the Complex Model or vehicle emissions testing will be used.

The nine areas in the extreme and serious ozone nonattainment categories currently comprise about 25 percent of the nation's gasoline market. However, because of the gasoline distribution system, surrounding areas will probably receive RFG as well. Taking these surrounding areas into consideration, the minimum market for RFG in 1995 is expected to be 21-23 percent of the current market.

Other areas are allowed to petition the EPA to opt-in to the RFG program. The most likely areas to request clean gasolines are the other less severe ozone non-attainment areas, which account for 20 to 35 percent of current gasoline demand. The only ozone non-attainment area in PADD IV is Salt Lake City. RFG demand associated with Salt Lake City is expected to be about 13 percent of total PADD IV gasoline demand in the year 2000.⁵

A significant motivation to enter the RFG opt-in programs will come in November 1993, when State Implementation Plans (SIPs) are required. In the SIPs, states will have to demonstrate their strategies for achieving compliance with clean air standards. Using clean gasolines to reduce vehicular emissions could be more attractive than other alternatives. The national market for clean gasolines is uncertain, but it could exceed 68 percent by the winter of year 2000.⁵

Besides requiring RFG in the covered ozone nonattainment areas, the CAAA requires that gasoline in all other areas not be any more polluting than it was in 1990. Without this "anti-dumping" provision, the potential exists for emissions from conventional gasoline (CG) to worsen as polluting fuel components are removed from and environmentally beneficial components are added to gasoline to be sold as RFG.

In addition to constraints on the quality of gasoline, the CAAA also limits highway diesel fuel to a maximum sulfur content of 0.05 weight percent and a minimum cetane index of 40, effective October 1, 1993.⁷

With the passage of the CAAA, environmental regulations will constrain the market, define product composition and performance, influence technology, change consumer expectations of performance, and determine the feasibility of various production and supply options.⁸ In short, domestic refinery operations will be driven by environmental regulations to a greater extent, by the consumer to a lesser extent.⁹

3. THE ORNL REFINERY YIELD MODEL

3.1 ORNL-RYM Capabilities

Studies of Rocky Mountain area petroleum product availability were performed with the ORNL Refinery Yield Model (ORNL-RYM), which is an enhanced personal computer version of the Refinery Yield Model of the Refinery Evaluation Modeling System.^{10,11,12,13} ORNL-RYM is a linear program that uses Haverly Systems software for matrix generation, optimization, and reporting.¹⁴

ORNL-RYM tracks octane, RVP, oxygen content, sulfur, benzene, aromatics, total olefins, distillation points, VOC, TAP, and NOX on all gasoline component streams. In separate data tables in ORNL-RYM, blending components for each gasoline grade are identified; blending values are assigned to each of up to 143 components; and blending specifications are set.

The oxygen content of gasoline can be controlled by purchase of MTBE (methyl tertiary butyl ether), Oxinol, TBA (tertiary butyl alcohol), ethanol, or methanol; or by internal production (with alcohol purchase) of MTBE, TAME (tertiary amyl methyl ether), and four other ethers.

Properties for distillates and jet fuels are handled conceptually the same as for gasoline. Properties can include gravity, aromatics content, paraffins content, naphthenes content, sulfur content, freezing point, luminometer number (which is correlated with smoke point), heat of combustion, hydrogen content, light cycle oil content, surface tension, pour point, cetane index, flash point, viscosities, RVP, distillation points, and diesel ignition improver content. The model also provides for several jet fuel additives for anti-icing, corrosion inhibition, and other functions.

Changes in crude feedstock are described in tables for crude quantity and assay. Changes in feedstock to individual process units are described in terms of different operation modes, each with different yields.

ORNL-RYM can be used to represent various regional refining configurations. Currently, ORNL-RYM includes 48 refining processes, which can be used to produce 40 different products from more than 100 crude oils. An investment module provides for the addition of processing capacity.

3.2 ORNL-RYM Simplifications

ORNL-RYM assumes that all refineries within a large region are interconnected. Consequently, ORNL-RYM has a tendency to over-optimize refinery operations. The over-optimization problem can sometimes be mitigated by focusing on changes in refining variables, rather than relying on the model to predict the exact value of variables. When ORNL-RYM is used to analyze uncharted refinery operations territory, it is sometimes advisable to interpret results with a more qualitative perspective.

ORNL-RYM has several simplifications which are particularly important to consider in the analysis of production of CAAA-compliant winter gasolines:

- (1) ORNL-RYM was updated in 1992 to represent the sulfur content property of gasolines.¹³ ORNL-RYM tends to produce RFGs with quite low sulfur contents, due largely to the production of low sulfur blendstocks by the FCC unit. The low sulfur property of RFGs may be coincident with refining strategies to meet emissions requirements by changing other properties, such as lowering the olefins content. Nevertheless, a review and possible revision are planned for sulfur content data for gasoline blendstocks.
- (2) Much of the control of aromatics in RFG will be via the naphtha reformer. Benzene reduction can be accomplished most simply by removing benzene precursors from reformer feed. In refining situations with ample ethers for octane improvement, the removed material can be blended directly into gasoline.¹⁵ ORNL-RYM does not have a representation of reformer feed fractionation to remove benzene precursors. Therefore, the ORNL-RYM refining options for benzene reduction in gasoline could be sub-optimal.
- (3) Economies of scale are not applied to the ORNL-RYM investment purchases.¹² Therefore, if a capacity addition is smaller than typical, ORNL-RYM would understate the cost, contributing to over-optimization. An example of the consequences of this simplification is shown in Table 3.1.

Table 3.1. Example of investment scaling in ORNL-RYM

Assume that economies of scale for a new reformat fractionator are represented by:

$$\text{Cost}_{\text{actual}} = \text{Cost}_T * (\text{Size}/\text{Size}_T)^{0.7},$$

where

$\text{Cost}_{\text{actual}}$ = On-site cost of new reformat fractionator;

Cost_T = On-site cost of typical reformat fractionator;

Size = Capacity of new reformat fractionator;

Size_T = Capacity of typical reformat fractionator;

0.7 is the power factor correlating cost and capacity.

If $\text{Cost}_T = \$10,000,000$ for $\text{Size}_T = 20$ thousand barrels per day (MBD), then the estimated cost for a 15 MBD reformat fractionator is:

$$\text{Cost}_{\text{actual}} = \$10,000,000 * (15 \text{ MBD}/20 \text{ MBD})^{0.7},$$

$$\text{Cost}_{\text{actual}} = \$8,176,000.$$

However, the ORNL-RYM investment cost, which does not account for economies of scale, is simply:

$$\text{Cost}_{\text{ORNL-RYM}} = \text{Cost}_T * (\text{Size}/\text{Size}_T)$$

$$\text{Cost}_{\text{ORNL-RYM}} = \$10,000,000 * (15 \text{ MBD}/20 \text{ MBD}) = \$7,500,000.$$

In this example, ORNL-RYM has underestimated the actual investment cost by more than 8 percent.

4. BLENDING GASOLINES TO SATISFY EMISSION SPECIFICATIONS

4.1 Emissions Models

For the study of winter refinery operations in the Rocky Mountain area, ORNL-RYM and supporting software were updated to blend gasolines to satisfy emissions constraints as defined by (1) the non-linear NOX model D1 of Advanced Computing Center of Argenta (ACCA);¹⁶ and (2) the Simple Model for winter TAP emissions published in the April 1992 *Federal Register's* EPA Supplemental Notice of Proposed Rulemaking.¹⁷ DOE sponsored development of the ACCA NOX model which is shown in Table 4.1. The Simple Model for winter TAP emissions is shown in Table 4.2.

Table 4.1.
NOX Model D1 of Advanced Computer Center of Argenta¹⁶

$$\begin{aligned} N(i) = \exp [& -2.43168044 \\ & + 0.00844363 \times \text{aromatics} \\ & + 0.00626083 \times \text{olefins} \\ & + 0.01090873 \times \text{RVP} \\ & + 0.00107160 \times \text{sulfur} \\ & + 0.03058621 \times \text{oxygen} \\ & - 0.00012928 \times \text{aromatics} \times \text{aromatics} \\ & - 0.00081353 \times \text{aromatics} \times \text{oxygen} \\ & - 0.00191451 \times \text{olefins} \times \text{oxygen} \\ & + 0.00226251 \times \text{RVP} \times \text{oxygen} \\ & - 0.00000148 \times \text{sulfur} \times \text{sulfur}] \end{aligned}$$

$$\text{NOX (gm/mi)} = \text{baseline known mass} \times N(i)/N(\text{baseline})$$

$$\text{NOX (gm/mi)} = 0.65999 \times N(i)/0.14253$$

For OG with 2 to 2.1 percent oxygen, oxygen = 0 in the above equation.

Table 4.2.
Simple Model for winter toxic air pollutants (TAPs)¹⁷
(milligrams per mile)

Total TAP emissions =

benzene + butadiene + formaldehyde + acetaldehyde + polycyclic organic material

To calculate TAP in the winter, the exhaust Volatile Organic Compounds (Exh VOC) must be calculated. There is no winter VOC emission limit for reformulated gasoline.

$$\text{Exh VOC}_s, \text{ grams/mile} = 0.46 * (1 - 0.127 * O_a / 2.7)$$

$$\text{Exh VOC}_w, \text{ grams/mile} = 0.68 * (1 - 0.127 * O_a / 2.7)$$

Benzene =

$$(1.818 + (0.9154 * B_a) + (0.109 * (A_a - B_a))) / 100 * 1000 * \text{Exh VOC}_w$$

$$1,3 \text{ Butadiene} = 0.00539 * 1000 * \text{Exh VOC}_w$$

$$\text{Formaldehyde}^{(1)(2)} = 0.1199 * \text{Exh VOC}_s * 1000 * (1 + (0.42/2.7) * O_a)$$

$$\text{Acetaldehyde}^{(1)(2)} = 0.00854 * \text{Exh VOC}_s * 1000 * (1 + (0.078/2.7) * O_a)$$

$$\text{Polycyclic organic material}^{(2)} = 0.00304 * \text{Exh VOC}_s * 1000$$

Abbreviations and definitions:

A = aromatics content, volume percent

B = benzene content, volume percent

O = oxygen content, weight percent

_a = current fuel being evaluated

_b = statutory baseline fuel

_s = summer

_w = winter

⁽¹⁾ Assumes MTBE is the oxygenate used.

⁽²⁾ The mass of formaldehyde, acetaldehyde and polycyclic organic material is the same in the winter as in the summer. Therefore, the summertime Exh VOC is used to calculate the wintertime emissions of these toxics.

4.2 Representation of Non-linear Emissions Models in a Linear Program

The method to represent non-linear emissions models within ORNL-RYM assumes that an emission value can be represented as a base emission value plus small linear emissions changes due

to small changes in gasoline properties. The method, proposed by Bob Warden of Chevron, U.S.A., consists of a sequence of steps:

Step 1: Choose a base gasoline.

The base gasoline might have the following base PROPERTY values: oxygen=2.1; aromatics=25; benzene=0.7; TAP =46.2131.

Step 2: Develop the blending equation (only the derivation for TAP is illustrated).

$$\begin{aligned} \text{TAP} &= \text{TAP}_{\text{base}} \\ &+ (\Delta\text{TAP}/\Delta\text{oxygen}) \times (\text{oxygen} - \text{oxygen}_{\text{base}}) \\ &+ (\Delta\text{TAP}/\Delta\text{aromatics}) \times (\text{aromatics} - \text{aromatics}_{\text{base}}) \\ &+ (\Delta\text{TAP}/\Delta\text{benzene}) \times (\text{benzene} - \text{benzene}_{\text{base}}) \end{aligned}$$

The $\Delta\text{TAP}/\Delta\text{PROPERTY}$ is an original coefficient (W_{original}).

For example, to determine $(\Delta\text{TAP}/\Delta\text{aromatics})$ for the base gasoline in Step 1 (aromatics=25 and TAP=46.2131), calculate TAP for that gasoline with aromatics content decreased by 0.1 volume percent (aromatics=24.9 and TAP=46.1463):

$$(\Delta\text{TAP}/\Delta\text{aromatics}) = (46.2131 - 46.1463)/(25 - 24.9) = 0.668$$

Step 3: Solve the linear program using the TAP constraint equation. For example,

$$\text{TAP} \leq 45.75 \text{ (for a 16 percent TAP reduction)}$$

$$\begin{aligned} \text{TAP} &= 46.2131 \\ &- 1.5342 \times (\text{oxygen} - 2.1) \\ &+ 0.6680 \times (\text{aromatics} - 25) \\ &+ 4.9419 \times (\text{benzene} - 0.7) \end{aligned}$$

One way of representing the latter equation is to calculate the TAP values for each gasoline blendstock and load the values in a gasoline component blending table.

Step 4: Given the linear program solution PROPERTY values, calculate the actual TAP using the emissions models. This step confirms whether the solution satisfies the TAP constraint.

Step 5: Given the linear program solution PROPERTY values, calculate new coefficients (W_{new}). Compare the original (W_{original}) and the new (W_{new}) coefficients for each PROPERTY.

Specify the unacceptable error percentage = ER%.

If $100\% \times |(W_{\text{original}} - W_{\text{new}})/W_{\text{original}}| > \text{ER}\%$, then go to Step 6. If not, then

ACCEPT LINEAR PROGRAM SOLUTION and STOP.

Step 6: Choose a new base gasoline with PROPERTY values equal to the linear program solution values. Go to Step 2.

The Warden method converges rapidly in the analysis of winter refinery operations in the Rocky Mountain area.

5. THE ROCKY MOUNTAIN AREA PETROLEUM SYSTEM

5.1 Characteristics of the Rocky Mountain Area Petroleum System

The updated ORNL-RYM and supporting software have been used to estimate the Rocky Mountain area petroleum product availability impacts for different PADD IV refining capacity scenarios in the winter of year 2000. For this study, the Rocky Mountain area is defined to consist of (1) domestic areas which supply crude oil and refined products to PADD IV and (2) domestic areas which are supplied crude oil and refined products by PADD IV. The Rocky Mountain area petroleum system includes the following activities:

PADD IV refineries manufacture products for consumers in PADDs II and IV and in eastern Washington.

PADD IV produces crude oils for refineries in PADDs II, III, and IV.

PADD II refineries manufacture products for consumers in PADD IV.

PADD III refineries manufacture products for consumers in PADD IV.

Washington refineries can manufacture products for eastern Washington consumers, who are normally supplied by PADD IV refineries.

The domestic refining and pipeline distribution systems that serve the Rocky Mountain area are summarized in Table 5.1.

Table 5.1. Domestic refining and distribution systems that serve the Rocky Mountain area ^{18,19,20,21,22}							
Region	Operating refineries (as of January 1, 1992)			Pipe- lines from PADD IV (winter MBD)		Pipe- lines to PADD IV (winter MBD)	
	N u m b e r	Total atmospheric distillation capacity (MBSD)	CI	C r u d e	P r o d u c t	C r u d e	P r o d u c t
PADD II (Midwest)	38	3,520	53	385	28+	45	41
PADD III (Gulf Coast)	69	7,298	57	103			42
PADD IV (part of the Rocky Mountain area)	16	528	44				
Washington state	7	559	45		73		

5.2 Petroleum Product Demand and Supply Options

For all scenarios, regional product demand is assumed to be identical to demand in January 1989^{23,24} (with gasoline demand adjusted to account for fuel economy differences²⁵). The shares of CG, OG, and RFG are based on NPC projections.⁵ In the Rocky Mountain area, Salt Lake City (a moderate ozone nonattainment area) is the only source of demand for RFG. CO non-attainment areas include Colorado Springs, Denver-Boulder, Fort-Collins-Loveland, Colorado; Missoula County, Montana; and Spokane, Washington.

Table 5.2 shows the demand requirements for gasoline and distillates that would normally be produced by refineries that supply the Rocky Mountain area. These demands are satisfied as shown in Table 5.3 and in Fig. 5.1.

Fig. 5.1
BASE YEAR 2000 WINTER GASOLINE/DISTILLATE SUPPLY
BALANCE IN THE ROCKY MOUNTAIN AREA (MBD)

Table 5.2. Winter demand requirements for gasoline and distillates in the Rocky Mountain area ^{23, 24} (Base Year 2000, MBD)				
	Demand source			Total
	PADD IV	PADD II	Washington state	
Motor gasoline	218.1	16.2	30.5	264.8
Aviation gasoline	0.8			0.8
Jet A	47.7	0.1	4.3	52.1
JP-8	5.0	3.8	2.3	11.1
Kerosene	0.6			0.6
No.2 diesel	62.3	7.3	3.8	73.4
No. 2 fuel oil	31.1	3.6	7.7	42.4
Total	365.6	31.0	48.6	445.2

Table 5.3. Winter supply sources for gasoline and distillates in the Rocky Mountain area^{23, 24}
(Base Year 2000, MBD)

Supply source	Demand source			Total
	PADD II	PADD IV	Washington state	
PADD II		26.5		26.5
PADD III		25.8		25.8
PADD IV	31.0	313.3	48.6	392.9
Total	31.0	365.6	48.6	445.2

One objective of the scenario studies is to satisfy total product demand at minimum cost by adjusting product slates for refineries in PADDs II, III, IV and in Washington state. Given reduced refining capacities for PADD IV, these studies consider combinations of the following options to satisfy total demand:

Increasing the utilization of PADD IV refineries;

Increasing the utilization of refineries in PADDs II and III and increasing the utilization of product pipelines from PADDs II and III to PADD IV;

Increasing the supply of products from western Washington state refineries to consumers in eastern Washington state who would otherwise be supplied by PADD IV refineries.

Because of the high cost and uncertainty of trucking product to the more remote areas of PADD II in the winter, it has been assumed that PADD IV refineries must maintain the normal level of product exports by pipeline to PADD II.

5.3 Economic Assumptions and Simplifications

The studies do not predict refinery closures. The reduced refining capacities for PADD IV simply provide an analysis framework for probing the flexibility of petroleum refining and distribution in the Rocky Mountain area. Reduced refining capacities result in increased product costs. If costs are passed to the consumer, demand may fall and other product suppliers may enter (or re-enter) the market over a period of time. However, these studies are concerned with very-short-term imbalances, and product cost increases are estimated without consideration of market adjustments.

The assumptions for product prices and raw material costs are the same for all scenarios. The average world oil price is assumed to be \$27.80 per barrel (66.2 cents per gallon, 1990 U.S. currency) for the year 2000.²⁶ The average world oil price is used as the reference to set ORNL-RYM prices for individual crude oils and products, such as those listed in Table 5.4. The crude and product price differentials in Table 5.4 have remained nearly constant despite a tenfold range of crude oil prices during the last twenty-five years, including the 1986 price collapse. The ORNL-RYM price of MTBE is based on the National Petroleum Council (NPC) refining study differential with respect to the expected price of gasoline.

Table 5.4. Hydrocarbon price differentials ²⁷	
Product	Relationship
MTBE	35.0 cents per gallon over unleaded regular motor gasoline
Unleaded premium gasoline	4.0 cents per gallon over unleaded regular motor gasoline
Unleaded regular motor gasoline	3.5 cents per gallon over No. 2 fuel oil
Jet A	3.0 cents per gallon over No. 2 fuel oil
No. 2 fuel oil	8% over crude oil
No. 6 fuel oil (0.7% sulfur)	77% of No. 2 fuel oil
Bunker fuel (3% sulfur)	68% of No. 2 fuel oil

5.4 Gasoline Quality Assumptions

Based on *Federal Register* guidance, it is assumed that winter RFG is produced to satisfy a 17 percent reduction in TAP (maximum TAP=45.8 mg/mi), relative to the winter baseline gasoline, and computed according to the Simple Model for TAP emissions.¹⁷ Section 10 will discuss the adequacy of this assumption for satisfying a 25 percent reduction in TAP emissions for the year 2000, as computed with a Complex Model. It is assumed that the maximum NOX level for RFG is the winter baseline NOX emission level (0.69 gm/mi).

In addition to the oxygenate requirement for OG, it is assumed that OG emissions of TAP and NOX will not exceed levels determined in ORNL-RYM analyses for CG produced in 1990 regional refinery operations. Likewise, it is assumed that TAP and NOX emissions for CGs produced in the year 2000 will not exceed 1990 CG levels.

5.5 Scenarios

In the base case, PADD IV refinery capacity is the same as reported on January 1, 1992,^{4,28} plus additional (sunk cost) capacity for desulfurization and sulfur recovery for production of ultra low sulfur diesel fuel. In the study scenarios, PADD IV refinery capacity is reduced from base case levels. Investment is not allowed in PADD IV, except for ether production for oxygenated gasolines.

In the base case and in all scenarios, PADDs II, III, and Washington refinery capacities are the same as reported on January 1, 1992,^{4,28} plus announced construction,²⁹ plus additional (sunk cost) capacity for desulfurization and sulfur recovery for production of ultra low sulfur diesel fuel, plus process unit investment as determined by ORNL-RYM. Three scenarios are investigated:

Scenario 1: Maximize Pipeline Utilization. Shipments of product are maximized in pipelines from PADDs II and III into PADD IV; and in the Chevron Pipeline from Pasco to Spokane, Washington.

Scenario 2: Maximize Product from Washington Refineries. Product flow from PADD IV to Washington state is reduced by 67 percent (equivalent to shut-down of the Yellowstone Pipeline from PADD IV to Washington). The supply loss is compensated by increased utilization of refineries in Washington.

Scenario 3: Minimum Required Refining Capacity. The PADD IV refinery configuration is the minimum required to satisfy product demand using any combination of supply options.

6. SCENARIO 1: MAXIMIZE PIPELINE UTILIZATION

In *Scenario 1: Maximize Pipeline Utilization*, ORNL-RYM is used to identify a minimum refinery system in PADD IV, with which product demand can be satisfied by using slack in the pipeline system and slack in refineries of other regions. If it is assumed that the pipeline capacities of Table 6.1 are sustainable (i.e., the capacities account for maintenance and other contingencies), then an additional 33 MBD of product could be delivered from alternate sources.

Table 6.1. Product pipeline slack for the Rocky Mountain area			
	Winter capacity for No. 2 fuel oil (MBD)	Base winter product mix throughput (MBD) ²³	Available slack (MBD)
PADD II to IV: Chase Pipeline ²⁰	40.8	50.6	30.0
PADD III to IV: Phillips Pipeline ²¹	39.8 ^a		
Pasco to Spokane, Washington: Chevron Pipeline ²²	15.0	12.0	3.0
Total	95.6	62.6	33.0

^aWinter capacity for product mix (typical batches of gasolines and distillates) is 42.3 MBD.

The *Scenario 1* gasoline and distillate supply balance shown in Table 6.2 and Fig. 6.1 was determined by minimizing refining costs region-by-region, beginning with PADD IV. PADD IV was selected as the starting point based on preliminary ORNL-RYM results which indicated that PADD IV costs would be so dominant that total system costs could be minimized by minimizing costs in PADD IV.

Given the maximum pipeline supply from PADDs II and III and the incremental supply from Washington, the PADD IV refining system total output was fixed. Within the constraints for total PADD IV output and total overall demand for individual products, PADD IV was allowed to produce the optimal mix of products. It was determined that PADD IV had to include at least all refineries with CI greater than 32. The minimum PADD IV system of Table 6.3 has an overall CI of 53, which is equal to the CI for PADD II and greater than the CI for Washington. This PADD IV system consists of twelve refineries, and has about 78 percent of the crude distillation capacity of the sixteen refineries in the actual system of January 1, 1992. Table 6.4 shows the four refineries which are not included in the system of *Scenario 1*.

Fig. 6.1

SCENARIO 1 GASOLINE/DISTILLATE SUPPLY BALANCE
IN THE ROCKY MOUNTAIN AREA (MBD)

Table 6.2. *Scenario 1*: supply balance
(MBD)

	Demand	Supply source			
		PADD IV	Washington	PADD II	PADD III
CG	133.5	98.1	3.0	32.4	
RFG	29.1	29.1			
OG	102.6	102.6			
Aviation gasoline	0.8	0.8			
Jet A	52.1	14.9		8.4	28.8
JP-8	11.1				11.1
Kerosene	0.6	0.6			
No. 2 diesel	73.4	73.4			
No. 2 fuel oil	42.4	42.4			
Total	445.6	361.9	3.0	40.8	39.9

Table 6.3. *Scenario 1: reduced PADD IV refinery system*
(refineries in shaded cells located in or near expected RFG demand area)

	Operating atmospheric crude oil distillation capacity (MBSD)	Conversion index
Conoco Inc., Commerce City, Colorado	50.0	38
Conoco Inc., Billings, Montana	52.0	61
Exxon Co. USA, Billings, Montana	44.0	76
Montana Refining Co., Great Falls, Montana	7.0	34
Amoco Oil Co., Salt Lake City, Utah	41.5	43
Chevron USA Inc., Salt Lake City, Utah	49.0	54
Pennzoil Producing Co., Roosevelt, Utah	8.5	99
Phillips 66 Co., Woods Cross, Utah	26.0	32.3
Frontier Refining Co., Cheyenne, Wyoming	40.8	52
Little America Refining Co., Evansville (Casper), Wyoming	25.5	41
Sinclair Oil Corp., Sinclair, Wyoming	55.0	38
Wyoming Refining Co., Newcastle, Wyoming	13.5	37
Total	412.8 (78% of PADD IV capacity of 1/1/92)	53

Table 6.4. PADD IV refineries not included in system of *Scenario 1*
(refineries in shaded cells located in or near expected RFG demand area)

	Operating atmospheric crude oil distillation capacity (MBSD)	Conversion index
Colorado Refining Co. Commerce City, Colorado	35.0	24
Cenex, Laurel, Montana	42.5	31.8
Big West Oil Co., North Salt Lake, Utah	25.0	20
Crysen Refining, Inc., Woods Cross, Utah	13.0	0
Total	115.5 (22% of PADD IV capacity of 1/1/92)	23

Table 6.2 shows that PADD IV satisfies the overall demand for all products except CG, Jet A, and JP-8. Of the remaining regions, Washington has the lowest production costs and is allowed to produce any combination of CG, Jet A, and JP-8 for its contribution. The optimal choice for Washington is 3 MBD of CG.

Finally, the remaining volumes of CG, Jet A, and JP-8 are allocated to PADDs II and III. Costs are minimized by allocating most of the jet fuels to PADD III. The remaining jet fuel and CG are produced in PADD II.

Production (marginal) cost changes for gasolines and distillates are shown in Table 6.5. PADD IV costs increase by about 10-11 cents per gallon. Washington costs do not increase because the incremental product volume is low. Depending on the product, costs in PADDs II and III change by -0.1 to +0.3 cents per gallon.

Appendix A provides details of regional refinery operations for *Scenario 1*, including total production of gasoline and distillates, gasoline properties, and impacts on refinery process investment.

The *Scenario 1* cost increases suggest that there is a substantial incentive for suppliers in Washington and in PADDs II and III to use alternate product distribution options. Such options are investigated in *Scenario 2*.

Table 6.5. <i>Scenario 1</i> : production cost changes (cents per gallon, relative to base case)				
	Supply source			
	PADD IV	Washington	PADD II	PADD III
CG	10.9	0	0	-0.1
RFG	9.8		0	-0.1
OG	9.5	0	0	-0.1
Aviation gasoline	10.9		0	-0.1
Jet A	11.4	0	0	0.3
JP-8			0	0.3
Kerosene	10.7		0	0.3
No.2 diesel	11.4	0	0.1	0.3
No. 2 fuel oil	10.0	0	-0.1	0.2

7. SCENARIO 2: MAXIMIZE PRODUCT FROM WASHINGTON REFINERIES

The reduced PADD IV refinery system of Table 7.1 (with CI of 54) is obtained by eliminating the refinery with the lowest CI in *Scenario 1*. This reduced refinery system consists of eleven refineries, and has about 73 percent of the crude distillation capacity of the sixteen refineries in the actual system of January 1, 1992. Table 7.2 shows the five refineries which are not included in this reduced PADD IV system.

ORNL-RYM shows that product demand cannot be satisfied by maximizing pipeline utilization with the reduced refinery system of Table 7.1. However, demand might be satisfied under the conditions of *Scenario 2: Maximize Product from Washington Refineries*.

Table 7.1. <i>Scenario 2: reduced PADD IV refinery system</i> (refineries in shaded cells located in or near expected RFG demand area)		
	Operating atmospheric crude oil distillation capacity (MBSD)	Conversion index
Conoco Inc., Commerce City, Colorado	50.0	38
Conoco Inc., Billings, Montana	52.0	61
Exxon Co. USA, Billings, Montana	44.0	76
Montana Refining Co., Great Falls, Montana	7.0	34
Amoco Oil Co., Salt Lake City, Utah	41.5	43
Chevron USA Inc., Salt Lake City, Utah	49.0	54
Pennzoil Producing Co., Roosevelt, Utah	8.5	99
Frontier Refining Co., Cheyenne, Wyoming	40.8	52
Little America Refining Co., Evansville (Casper), Wyoming	25.5	41
Sinclair Oil Corp., Sinclair, Wyoming	55.0	38
Wyoming Refining Co., Newcastle, Wyoming	13.5	37
Total	386.8 (73% of PADD IV capacity of 1/1/92)	54

Table 7.2. PADD IV refineries not included in system of <i>Scenario 2</i> (refineries in shaded cells located in or near expected RFG demand area)		
	Operating atmospheric crude oil distillation capacity (MBSD)	Conversion index
Colorado Refining Co. Commerce City, Colorado	35.0	24
Cenex, Laurel, Montana	42.5	31.8
Big West Oil Co., North Salt Lake, Utah	25.0	20
Crysen Refining, Inc., Woods Cross, Utah	13.0	0
Phillips 66 Co., Woods Cross, Utah	26.0	32.3
Total	141.5 (27% of PADD IV capacity of 1/1/92)	25

Consumers in eastern Washington receive refined product from barges towed up the Columbia River and through the Yellowstone and Chevron Pipelines from PADD IV. Both the Yellowstone and Chevron Pipelines face occasional capacity constraints. During high-demand months, additional product must be provided through alternative, more expensive means, such as by truck or barge. In 1990, the Yellowstone Pipeline was capacity constrained for all months except January, February, March, and December.²⁴

The issue of loss of supply from the Yellowstone Pipeline was studied in the early 1980s. In *Petroleum Supply and Distribution Systems in Washington State*,³⁰ the Washington State Energy Office (WSEO) reports that "If the refined products supplied by the Yellowstone Pipeline were cut off entirely and if adequate supplies were available in western Washington to replenish them, then the barge supply system could move products from western Washington to Pasco. There is enough flexibility in the system to solve this type of a supply problem."

Based on the WSEO report, *Scenario 2* assumes that it is feasible for Washington refineries to supply additional product to the Spokane area in an amount equivalent to base case flow in the Yellowstone Pipeline (32.7 MBD). *Scenario 2* further assumes that the replacement supply can be delivered to Spokane by full utilization of the Chevron Pipeline from Pasco, and by truck (at least 125 truck loads per day).

Given delivery of product by truck from Pasco, the estimated increase in the cost of delivery of product from Washington refineries to Spokane is 5.3 cents per gallon.^{18,31,32} Plausible trial-and-error assumptions are:

The total increased costs for Washington suppliers (refining plus delivery) is less than the total increased costs of products supplied by PADD IV; therefore, Washington state suppliers will maximize delivery of product to Spokane.

The total increased costs for PADD II and III suppliers is less than the total increased costs of products supplied by PADD IV; therefore, PADD II and PADD III suppliers will maximize pipeline delivery of products to PADD IV.

Scenario 2 also assumes that the Phillips Pipeline from PADD III to PADD IV can deliver product at sustainable rates approximately equal to the winter capacity for product mix.

The *Scenario 2* gasoline and distillate supply balance shown in Table 7.3 and Fig. 7.1 was determined by minimizing refining costs region-by-region, beginning with PADD IV. Given the maximum pipeline supply from PADDs II and III and the additional supply from Washington, the PADD IV refining system total output was fixed. Within the constraints for total PADD IV output and total overall demand for individual products, PADD IV was allowed to produce the optimal mix of products.

Table 7.3 shows that PADD IV satisfies the overall demand for RFG, aviation gasoline, kerosene, and No. 2 diesel. Of the remaining regions, Washington has the lowest production costs and is allowed to produce any combination of CG, OG, Jet A, JP-8, and No. 2 fuel oil for its contribution; the optimal choice for Washington includes some of each of these products.

Finally, the remaining volumes of CG, Jet A, JP-8, and No. 2 fuel oil are allocated to PADDs II and III. Costs are minimized by allocating most of the jet fuel production to PADD III. The remaining jet fuel, CG, and No. 2 fuel oil are produced in PADD II.

Table 7.3. Scenario 2: supply balance (MBD)					
	Demand	Supply source			
		PADD IV	Washington	PADD II	PADD III
CG	134.4	89.9	16.8	27.7	
RFG	29.4	29.4			
OG	101.0	95.5	5.5		
Aviation gasoline	0.8	0.8			
Jet A	52.1	3.0	4.3	10.5	34.3
JP-8	11.1	0.4	2.3		8.4
Kerosene	0.6	0.6			
No. 2 diesel	73.4	73.4			
No. 2 fuel oil	42.4	36.0	3.8	2.6	
Total	445.2	329.0	32.7	40.8	42.7 ^a

^aTarget rate was 42.3 MBD. Sources of the difference (less than 1 percent) include trial-and-error adjustments to account for changes in gasoline fuel economy.

Fig. 7.1
SCENARIO 2 GASOLINE/DISTILLATE SUPPLY BALANCE
IN THE ROCKY MOUNTAIN AREA (MBD)

Production (marginal) cost changes for gasolines and distillates are shown in Table 7.4. PADD IV costs increase by about 6-7 cents per gallon. Depending on the product, costs in PADDs II and III change by -0.1 to +0.3 cents per gallon.

Washington refining costs increase by about 0.1-0.5 cents per gallon. Including the transportation cost increase (5.3 cents per gallon, by truck), the total cost increase for product produced in Washington refineries and delivered to Spokane area consumers is 5.4-5.8 cents per gallon. The total cost increase for Washington suppliers is less than the total increased costs of products supplied by PADD IV, which supports the assumption that Washington suppliers will maximize delivery of product to Spokane.

Table 7.4. <i>Scenario 2: production cost changes</i> (cents per gallon, relative to base case)				
	Supply source			
	PADD IV	Washington	PADD II	PADD III
CG	6.4	0.5	0	-0.1
RFG	6.0		0	-0.1
OG	5.9	0.3	0	-0.1
Aviation gasoline	6.2		0	-0.1
Jet A	6.4	0.1	0	0.3
JP-8			0	0.3
Kerosene	6.0		0	0.3
No.2 diesel	6.8	0.1	0.1	0.3
No. 2 fuel oil	6.4	0.1	-0.1	0.2

8. SCENARIO 3: MINIMUM REQUIRED REFINING CAPACITY

In *Scenario 2*, maximum product volumes are supplied by refineries of PADDs II, III, and Washington. Additional volumes cannot be supplied because of physical limitations of the product delivery systems, and PADD IV refineries must produce 329 MBD of gasolines and distillates.

Scenario 3: Minimum Required Refining Capacity assumes that maximum product volumes are provided by PADDs II, III, and Washington, and that PADD IV refineries must produce the balance of 329 MBD. Without regard for product cost impacts, refineries are eliminated, one-by-one, from the refining system of *Scenario 2*. Refineries are eliminated in order of lowest CI. As refineries are eliminated, the remaining refineries must increase process capacity utilization to maintain production of 329 MBD.

ORNL-RYM shows that the reduced refinery system of Table 8.1 is the minimum required to satisfy demand using any combination of supply options. The reduced PADD IV system of *Scenario 3* consists of nine refineries, and has about 69 percent of the crude distillation capacity of the sixteen refineries in the actual system of January 1, 1992. Elimination of the refinery with the next lowest CI (Conoco Inc., Commerce City, Colorado) would result in a system which could not satisfy product demand because of insufficient crude processing capacity. Table 8.2 shows the five refineries which are not included in the reduced PADD IV system of *Scenario 3*.

Industry analysts have estimated that, for worst case scenarios, 104 to 185 MBD of PADD IV refining capacity could be shut-down as a result of clean air and energy tax legislation.^{33,34} *Scenario 3* indicates that there could be product availability problems with capacity shut-downs on the high side of industry projections. Assuming that the more complex refineries have a higher survival probability, *Scenario 3* suggests that, with shut-down of more than 162 MBD of refining capacity, the Rocky Mountain area petroleum system will not have the technical capability to satisfy winter product demand.

Table 8.1. *Scenario 3: reduced PADD IV refinery system*
(refineries in shaded cells located in or near expected RFG demand area)

	Operating atmospheric crude oil distillation capacity (MBSD)	Conversion index
Conoco Inc., Commerce City, Colorado	50.0	38
Conoco Inc., Billings, Montana	52.0	61
Exxon Co. USA, Billings, Montana	44.0	76
Amoco Oil Co., Salt Lake City, Utah	41.5	43
Chevron USA Inc., Salt Lake City, Utah	49.0	54
Pennzoil Producing Co., Roosevelt, Utah	8.5	99
Frontier Refining Co., Cheyenne, Wyoming	40.8	52
Little America Refining Co., Evansville (Casper), Wyoming	25.5	41
Sinclair Oil Corp., Sinclair, Wyoming	55.0	38
Total	366.3 (69% of PADD IV capacity of 1/1/92)	55

Table 8.2. PADD IV refineries not included in system of *Scenario 3*
(refineries in shaded cells located in or near expected RFG demand area)

	Operating atmospheric crude oil distillation capacity (MBSD)	Conversion index
Colorado Refining Co. Commerce City, Colorado	35.0	24
Montana Refining Co., Great Falls, Montana	7.0	34
Cenex, Laurel, Montana	42.5	31.8
Big West Oil Co., North Salt Lake, Utah	25.0	20
Crysen Refining, Inc., Woods Cross, Utah	13.0	0
Phillips 66 Co., Woods Cross, Utah	26.0	32.3
Wyoming Refining Co., Newcastle, Wyoming	13.5	37
Total	162 (31% of PADD IV capacity of 1/1/92)	26

9. CRUDE OIL DEMAND IMPACTS

9.1 Crude Oil Re-routing Possibilities

A major objective of the study of Rocky Mountain petroleum availability is to identify problems and costs associated with re-routing crude oils to alternate destinations, thereby avoiding shut-in crude oil production capacity. Potential re-routing problems and costs are evaluated for *Scenario 2: Maximize Product from Washington Refineries*, because the greatest changes in regional demand for crudes and other raw materials occur in *Scenario 2*. Table 9.1 summarizes the changes in crude oil input to refineries in *Scenario 2*, relative to base year 2000.

Table 9.1. Changes in crude oil input to Rocky Mountain area refineries (<i>Scenario 2</i> relative to base year 2000)	
Refining region	Change in crude input (MBD)
PADD II	18.9
PADD III	18.2
PADD IV	-69.8
Washington state	33

In all scenarios, ORNL-RYM selects individual crudes from crude slates which match, as closely as possible, the geographical source, overall sulfur content, and gravity of the 1989 regional crude slates. Alternatively, Table 9.1 shows that it may be possible to satisfy the increased crude oil demands in PADDs II, III, and Washington by re-routing crude released from PADD IV refinery demands.

A plausible re-routing option is to use additional capacity in crude oil pipelines, relative to flow during January 1989. Estimates of slack capacity are shown in Table 9.2.^{23,35}

Table 9.2. Estimated crude oil pipeline operating slack (MBD)			
Pipeline route	Observed operating maximum/date ³⁵	Base flow, January 1989 ²³	Estimated slack
PADD IV to PADD II	219 (March 1988)	150	69
PADD IV to PADD III	98 (February 1988)	65	33

9.2 Re-routing Crude Oil from PADD IV to PADD III

Based on minimizing the increase in production (marginal) costs, ORNL-RYM indicates that the best crude re-routing scheme is to fully utilize the slack in pipelines from PADD IV to PADD III. In this scheme, 33 MBD of Utah crude oil displaces 14.8 MBD of Alaska North Slope crude and 18.2 MBD of Texas West Intermediate. As discussed in Section 9.4, the displaced Alaska crude compensates for increased crude oil demand in Washington (i.e., there is a 14.8 MBD netback for Washington). The displaced Texas West Intermediate is equivalent to the increased crude requirement for *Scenario 2*, as shown in Table 9.1. Compared to *Scenario 2*, the costs of products are not significantly changed by re-routing and refining crude in PADD III.

Figs. 9.1 and 9.2 show the effects of re-routing crude oil from PADD IV to PADD III. In base year 2000, PADD IV supplies 64.8 MBD of crude oil to PADD III. In *Scenario 2*, PADD IV supplies an additional 33 MBD to PADD III, for a total of 97.8 MBD from PADD IV to PADD III.

9.3 Re-routing Crude Oil from PADD IV to PADD II

Given the re-routing of 33 MBD of crude from PADD IV to PADD III, PADD IV has 36.8 MBD remaining for re-routing to PADD II. PADD IV supplies 36.8 MBD of Montana crude oil to PADD II, displacing 36.8 MBD of Canadian crude. As discussed in Section 9.4, part of the displaced Canadian crude provides an off-set for Washington imports (i.e., there is a 17.9 MBD netback for Washington). The remaining portion of displaced Canadian crude (18.9 MBD) is equivalent to the increased crude requirement for *Scenario 2*, as shown in Table 9.1. Compared to *Scenario 2*, re-routing and refining crude in PADD II causes minor changes (less than 0.03 cents per gallon) in the costs of products.

Figs. 9.1 and 9.2 show the effects of re-routing crude oil from PADD IV to PADD II. In base year 2000, PADD IV supplies 150 MBD of crude oil to PADD II. In *Scenario 2*, PADD IV supplies an additional 36.8 MBD to PADD II, for a total of 186.8 MBD from PADD IV to PADD II.

Fig. 9.1
INTER-REGIONAL WINTER CRUDE OIL MOVEMENTS
IN THE ROCKY MOUNTAIN AREA (BASE YEAR 2000, MBD)

Fig. 9.2
INTER-REGIONAL WINTER CRUDE OIL MOVEMENTS
IN THE ROCKY MOUNTAIN AREA (SCENARIO 2)

9.4 Re-routing Crude Oil for Washington State

Table 9.1 shows that, in *Scenario 2*, Washington refineries have an increased crude requirement of 33 MBD (Alaska North Slope crude). Part of this requirement can be satisfied by 14.8 MBD released from PADD III in the crude re-routing scheme (Section 9.2). The remainder of the requirement can be satisfied by 17.9 MBD of Canadian crude, which balances the Canadian crude volume released from PADD II (Section 9.3). Compared to *Scenario 2*, re-routing and refining crude in Washington causes the cost of products to increase by up to 0.2 cents per gallon, as shown in Table 9.3.

Figs. 9.1 and 9.2 show the re-routing of crude oil for Washington. PADD IV does not supply crude oil directly to Washington in either the base year or in *Scenario 2*. However, in *Scenario 2*, there is a 32.7 MBD crude netback for Washington, due to PADD IV's displacement of crudes in PADDs II and III.

Table 9.3. Cost changes for re-routing crude oil for Washington state (cents per gallon, relative to <i>Scenario 2</i>)	
CG	0.1
OG	0.2
Jet A	0
JP-8	0
No.2 diesel	0
No. 2 fuel oil	0

9.5 Summary Re-routing of Crude Oil

PADD IV crude oil production can be maintained by re-routing crude released from PADD IV refinery demands to satisfy increased crude oil demands in PADDs II, III, and Washington. Though not necessarily optimal, the suggested re-routing scheme causes only minor product cost increases in Washington. The re-routing activities are:

69.8 MBD of crude become available in PADD IV:

- A. Of the 69.8 MBD, 33 MBD of Utah crude is pipelined to PADD III
  - 1. Of the 33 MBD, 18.2 MBD is used to satisfy increased refinery demand
  - 2. Of the 33 MBD, 14.8 MBD is used to off-set increased demand in Washington

- B. Of the 69.8 MBD, 36.8 MBD of Montana crude is pipelined to PADD II
  - 1. Of the 36.8 MBD, 18.9 MBD is used to satisfy increased refinery demand
  - 2. Of the 36.8 MBD, 17.9 is used to off-set demand for Canadian crude in Washington

10. SATISFYING EMISSIONS REQUIREMENTS OF THE YEAR 2000

10.1 TAP Emissions and the Complex Model

The CAAA requires that, in the year 2000 and beyond, TAP emissions for RFG be 25 percent lower than the emissions from baseline gasoline, on an annual basis. The CAAA also specifies that the EPA Administrator may adjust the 25 percent reduction level to provide for lesser or greater reductions based on technological feasibility, considering the cost of achieving such reductions. In no case can the required reduction be less than 20 percent.³⁶

In the analysis of Rocky Mountain area petroleum product availability, it is assumed that winter RFG is produced to satisfy a 17 percent reduction in TAP, relative to the winter baseline gasoline, *and computed according to the Simple Model for TAP emissions*. The average weightings for summer and winter gasoline¹⁷ suggest that, to achieve an annual TAP reduction of 25 percent given a winter TAP reduction of 17 percent, the required reduction for summer gasoline would be 34 percent.^a However, the Simple Model may substantially understate TAP reductions for the year 2000.

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^aIn the NPC refining study, RFG summer TAP reduction targets are 32 percent for PADD II, 31 percent for PADD III, and 30 percent for PADD IV.⁵

After the Rocky Mountain studies began, EPA released the October 1992 version of the Complex Model.⁶ In February 1993, EPA provided guidance for use of a modified Complex Model to estimate winter TAP emissions (winter gasolines are assigned default RVP values of 8.7 psi). Table 10.1 shows that TAP reductions for the Rocky Mountain winter RFGs are at least 25 percent below baseline gasoline emissions when computed with the modified Complex Model of October 1992. Furthermore, using the Complex Model, the TAP emissions of Rocky Mountain CGs and OGs do not exceed the TAP emissions of 1990 gasolines. Importantly, the Simple Model limitations for TAP have resulted in Rocky Mountain study gasolines with TAP characteristics which satisfy year 2000 requirements, according to recent versions of the Complex Model.

Table 10.1. TAP reductions for Rocky Mountain winter RFGs, computed by modified Complex Model of October 1992			
	Base case year 2000	<i>Scenario 1</i>	<i>Scenario 2</i>
PADD II	26	25	25
PADD III	28	28	28
PADD IV	45	42	37

10.2 Difficulties in Satisfying Emissions Constraints

CAAA product quality regulations do not increase the difficulty of satisfying most emissions reduction constraints in the scenarios. The only binding emissions constraints are for:

PADD II NOX for CG and RFG, in base year 2000 and in *Scenarios 1* and 2 (see Appendix Tables A.2 and B.2). Compared to the base year, the scenarios have a 0.4 percent increase in the marginal cost for reduction of NOX.

Washington state NOX for CG, in base year 2000 and in *Scenarios 1* and 2 (see Appendix Tables A.5 and B.5). Marginal costs for reduction of NOX are the same in the base case and in *Scenario 1*. Compared to the base year, *Scenario 2* has a 4 percent increase in the marginal cost for reduction of NOX.

As shown in Tables 10.2 and 10.3, process investments are slightly higher, relative to the base year 2000, in regions with binding emissions constraints.

Table 10.2. <i>Scenario 1</i> impact on regional refinery investment (relative to base year 2000, MBD)				
	PADD II	PADD III	PADD IV	Washington
Butene isomerization	+1.5			+0.1
MTBE	+0.7			
Aromatics recovery				+0.2

Table 10.3. <i>Scenario 2</i> impact on regional refinery investment (relative to base year 2000, MBD)				
	PADD II	PADD III	PADD IV	Washington
Butene isomerization	+0.9			+0.8
MTBE	+0.5			+0.3
Aromatics recovery				+1.5
Visbreaker				+32

11. CONCLUSIONS

Studies of Rocky Mountain area petroleum product availability with reduced PADD IV refining capacities have been performed with ORNL-RYM, a linear program which has been updated to blend gasolines to satisfy constraints on NOX and winter TAP emissions. The studies do not predict refinery closures in PADD IV. Rather, the reduced refining capacities provide an analytical framework for probing the flexibility of petroleum refining and distribution.

The study scenarios are based on product demand for winter of the year 2000, selected because of DOE's concerns about adequate supplies of essential heating oils and diesel fuels. Typically, winter demand for PADD IV products is low, with low facility utilization, and with greater flexibility to obtain product from other regions. The demand conditions are conducive to depressed utilization of PADD IV refineries, and perhaps to depressed economic performance. The minimum refinery utilizations to satisfy winter demand are not sufficient to meet summertime product demand.

Reduced PADD IV refining capacities have been studied in three scenarios:

Scenario 1: Maximize Pipeline Utilization: A twelve refinery PADD IV system has been identified in which product demand can be satisfied by using slack in the pipeline system and in refineries of other regions. PADD IV refinery capacity is reduced by 116 MBD or 22 percent. Although production (marginal) costs change very little in other regions, *production costs increase in PADD IV by 10-11 cents per gallon of product* in this scenario. CAAA product quality regulations do not increase the difficulty of satisfying most emissions reduction constraints in *Scenario 1*. Compared to the base year 2000, *Scenario 1* has only a 0.4 percent increase in the marginal cost for reduction of NOX for CG and RFG in PADD II.

Scenario 2: Maximize Product from Washington Refineries: An eleven refinery PADD IV system has been identified in which it is necessary to maximize the deliveries of product from Washington refineries to consumers in eastern Washington. PADD IV refinery capacity is reduced by 142 MBD or 27 percent. In this scenario, *production costs in PADD IV increase by about 6-7 cents per gallon of product*. Including transportation cost increases, the total cost increase for product refined in Washington and delivered to Spokane area consumers is about 5-6 cents per gallon. CAAA product quality regulations do not increase the difficulty of satisfying most emissions reduction constraints in *Scenario 2*. Compared to the base year 2000, *Scenario 2* has only a 0.4 percent increase in the marginal cost for reduction of NOX for CG and RFG in PADD II. There is a 4 percent increase in the marginal cost of reduction of NOX in CG produced in Washington state.

Scenario 3: Minimum Required Refining Capacity: A nine refinery PADD IV system has been identified as a *system of minimum required refining capacity*. Refinery capacity is reduced by 162 MBD or 31 percent. Elimination of one additional refinery would result in a system which could not satisfy product demand because of insufficient crude processing capacity.

For *Scenario 2*, the scenario with the greatest change in regional demands for crude oils, the studies show that PADD IV crude oil production can be maintained by re-routing crude released

from PADD IV refinery demands to satisfy increased crude oil demands in PADDs II, III, and in Washington. The re-routing scheme causes only minor product cost increases in Washington.

Industry analysts have estimated that, for worst case scenarios, 104 to 185 MBD (20 to 35 percent) of PADD IV refining capacity could be shut-down as a result of clean air and energy tax legislation.^{33,34} Given these industry projections, the scenario study results support the following conclusions:

The Rocky Mountain area petroleum system would have the capability to satisfy winter product demand, with PADD IV refinery capacity shut-downs in the middle of the range of industry projections.

The Rocky Mountain area petroleum system would not have the capability to satisfy winter product demand, with PADD IV refinery capacity shut-downs in the high end of the range of industry projections

PADD IV crude oil production can be maintained by re-routing crude released from PADD IV refinery demands to satisfy increased crude oil demands in PADDs II, III, and Washington. This conclusion holds for all scenarios.

CAAA product quality regulations generally do not increase the difficulty of satisfying winter emissions reduction constraints in the scenarios.

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APPENDIX A.
REFINERY OPERATING DETAILS FOR SCENARIO 1:
MAXIMIZE PIPELINE UTILIZATION

Table A.1. <i>Scenario 1</i> impact on regional total production of gasolines and distillates (MBD)								
	PADD II		PADD III		PADD IV		Washington	
	B a s e 2 0 0 0	S c e n a r i o 1	B a s e 2 0 0 0	S c e n a r i o 1	B a s e 2 0 0 0	S c e n a r i o 1	B a s e 2 0 0 0	S c e n a r i o 1
CG	727	749	1041	1041	125	98.1	36.7	39.7
RFG	983	980	1977	1977	27.6	29.1		
OG	106	97	83.7	83.7	89.6	103	159	159
Aviation gasoline	4.6	3.9	9.7	9.7		0.8		
Jet A	177	186	677	705	29.4	14.9	79	79
JP-8	17.8	17.8	93.8	82.2	11.0			
Kerosene	30.7	30.7	55.1	55.1	0.6	0.6		
No. 2 diesel	606	606	1012	1010	70.2	73.4	49.3	49.3
No. 2 fuel oil	107	105	311	311	40.5	42.4	49.3	49.3
Total	2759	2775	5261	5275	394	362	374	377
Scenario impact	+16		+14		-32		+3	

Table A.2. <i>Scenario 1</i> impact on PADD II gasoline properties (shaded cells indicate binding emissions constraints ^a)						
	CG		RFG		OG	
	B a s e 2 0 0 0	S c e n a r i o 1	B a s e 2 0 0 0	S c e n a r i o 1	B a s e 2 0 0 0	S c e n a r i o 1
Octane, (R+M)/2	88.5	88.6	88.3	88.2	88.2	88.2
RVP, psi	13	13	13	13	13	13
Aromatics, vol %	28.2	28.0	24.4	24.6	31.0	30.8
Benzene, vol %	1.6	1.6	0.7	0.7	1.0	1.0
Olefins, vol %	12.4	11.9	10.5	10.7	4.5	6.0
Sulfur, ppm	233	236	144	143	182	172
T50, °F	184	184	182	182	190	191
T90, °F	325	325	322	324	316	315
Oxygen, wt %	0	0	2.16	2.16	2.7	2.7
Specific gravity	.7222	.7219	.7360	.7364	.7502	.7501
mpg factor	.978	.978	.965	.966	.969	.969
NOX, gm/mi	.6875	.6858	.6733	.6732	.6403	.6424
TAP, mg/mi	56.75	56.57	45.69	45.77	50.58	50.36

^aAs suggested by Step 4 of the convergence method in Section 4.2, there can be slight differences between the model-derived emissions value and the actual emissions values. For this reason, it is possible for NOX values to be binding at a single value in the model, while the actual NOX values are slightly different.

Table A.3.
Scenario 1 impact on PADD III gasoline properties

	CG		RFG		OG	
	B a s e 2 0 0 0	S c e n a r i o 1	B a s e 2 0 0 0	S c e n a r i o 1	B a s e 2 0 0 0	S c e n a r i o 1
Octane, (R+M)/2	88.6	88.6	87.4	87.4	89.2	89.1
RVP, psi	12	12	12	12	12	12
Aromatics, vol %	28.6	28.6	21.8	21.9	33.4	32.4
Benzene, vol %	1.6	1.6	0.7	0.7	1.2	1.2
Olefins, vol %	13.5	13.3	7.6	7.6	2.9	3.7
Sulfur, ppm	167	161	230	230	87	85
T50, °F	182	182	187	187	196	196
T90, °F	329	325	318	318	308	310
Oxygen, wt %	0	0	2.26	2.26	2.7	2.7
Specific gravity	.7270	.7269	.7325	.7328	.7513	.7490
mpg factor	.983	.983	.961	.962	.969	.968
NOX, gm/mi	.6635	.6602	.6892	.6892	.5882	.5908
TAP, mg/mi	56.93	56.92	43.74	43.87	53.12	52.28

Table A.4.
Scenario 1 impact on PADD IV gasoline properties

	CG		RFG		OG	
	B a s e 2 0 0 0	S c e n a r i o 1	B a s e 2 0 0 0	S c e n a r i o 1	B a s e 2 0 0 0	S c e n a r i o 1
Octane, (R+M)/2	87.2	87.6	88.1	88.1	88.7	86.7
RVP, psi	12.3	12.3	12.3	12.3	12.3	12.3
Aromatics, vol %	23.2	22.5	21.3	20.3	18.6	21.8
Benzene, vol %	1.2	1.3	0.6	0.6	0.7	0.7
Olefins, vol %	12.6	11.7	1.3	3.4	19.5	13.2
Sulfur, ppm	256	298	74	100	188	140
T50, °F	184	183	188	187	190	190
T90, °F	330	327	311	312	319	321
Oxygen, wt %	0	0	2.1	2.1	2.7	2.7
Specific gravity	.7230	.7211	.7369	.7313	.7322	.7365
mpg factor	.980	.978	.967	.962	.956	.960
NOX, gm/mi	.6821	.6843	.6169	.6320	.6831	.6449
TAP, mg/mi	51.06	50.44	43.16	42.55	40.90	43.40

Table A.5. <i>Scenario 1</i> impact on Washington state gasoline properties (shaded cells indicate binding emissions constraints ^a)				
	CG		OG	
	B a s e 2 0 0 0	S c e n a r i o 1	B a s e 2 0 0 0	S c e n a r i o 1
Octane, (R+M)/2	90.1	89.8	88.8	88.8
RVP, psi	13	12	12.6	13
Aromatics, vol %	27.8	29.0	25.7	25.4
Benzene, vol %	0.4	0.5	1.3	1.3
Olefins, vol %	7.3	7.0	5.8	5.9
Sulfur, ppm	230	288	88	70
T50, °F	186	186	184	183
T90, °F	319	318	321	322
Oxygen, wt %	0	0	2.7	2.7
Specific gravity	.7238	.7270	.7412	.7403
mpg factor	.980	.983	.962	.962
NOX, gm/mi	.6648	.6685	.6002	.5935
TAP, mg/mi	49.66	48.15	48.36	50.98

^aAs suggested by Step 4 of the convergence method in Section 4.2, there can be slight differences between the model-derived emissions value and the actual emissions values. For this reason, it is possible for NOX values to be binding at a single value in the model, while the actual NOX values are slightly different.

APPENDIX B.
REFINERY OPERATING DETAILS FOR SCENARIO 2:
MAXIMIZE PRODUCT FROM WASHINGTON REFINERIES

Table B.1. <i>Scenario 2 impact on regional total production of gasolines and distillates (MBD)</i>								
	PADD II		PADD III		PADD IV		Washington	
	B a s e 2 0 0 0	S c e n a r i o 2	B a s e 2 0 0 0	S c e n a r i o 2	B a s e 2 0 0 0	S c e n a r i o 2	B a s e 2 0 0 0	S c e n a r i o 2
CG	727	745	1041	1041	125	89.9	36.7	53.5
RFG	983	980	1977	1977	27.6	29.4		
OG	106	97	83.7	83.7	89.6	95.5	159	165
Aviation gasoline	4.6	3.9	9.7	9.7		0.8		
Jet A	177	188	677	711	29.4	3.0	79	83.3
JP-8	17.8	17.8	93.8	79.5	11.0			2.3
Kerosene	30.7	30.7	55.1	55.1	0.6	0.6		
No. 2 diesel	606	606	1012	1010	70.2	73.4	49.3	49.3
No. 2 fuel oil	107	107	311	311	40.5	36.0	49.3	53.1
Total	2759	2775	5261	5278	394	329	374	407
Scenario impact	+16		+17		-66		+33	

Table B.2. <i>Scenario 2 impact on PADD II gasoline properties</i> (shaded cells indicate binding emissions constraints ^a)						
	CG		RFG		OG	
	B a s e 2 0 0 0	S c e n a r i o 2	B a s e 2 0 0 0	S c e n a r i o 2	B a s e 2 0 0 0	S c e n a r i o 2
Octane, (R+M)/2	88.5	88.6	88.3	88.2	88.2	88.2
RVP, psi	13	13	13	13	13	13
Aromatics, vol %	28.2	28.1	24.4	24.6	31.0	30.8
Benzene, vol %	1.6	1.6	0.7	0.7	1.0	1.0
Olefins, vol %	12.4	12.0	10.5	10.6	4.5	5.6
Sulfur, ppm	233	235	144	143	182	172
T50, °F	184	184	182	182	190	190
T90, °F	325	324	322	322	316	316
Oxygen, wt %	0	0	2.16	2.16	2.7	2.7
Specific gravity	.7222	.7220	.7360	.7364	.7502	.7500
mpg factor	.978	.978	.965	.966	.969	.969
NOX, gm/mi	.6875	.6863	.6733	.6734	.6403	.6462
TAP, mg/mi	56.75	56.68	45.69	45.77	50.58	50.29

^aAs suggested by Step 4 of the convergence method in Section 4.2, there can be slight differences between the model-derived emissions value and the actual emissions values. For this reason, it is possible for NOX values to be binding at a single value in the model, while the actual NOX values are slightly different.

Table B.3.
Scenario 2 impact on PADD III gasoline properties

	CG		RFG		OG	
	B a s e 2 0 0 0	S c e n a r i o 2	B a s e 2 0 0 0	S c e n a r i o 2	B a s e 2 0 0 0	S c e n a r i o 2
Octane, (R+M)/2	88.6	88.6	87.4	87.4	89.2	89.0
RVP, psi	12	12	12	12	12	12
Aromatics, vol %	28.6	28.6	21.8	21.9	33.4	32.2
Benzene, vol %	1.6	1.6	0.7	0.7	1.2	1.2
Olefins, vol %	13.5	13.2	7.6	7.6	2.9	3.9
Sulfur, ppm	167	159	230	229	87	85
T50, °F	182	182	187	187	196	195
T90, °F	329	329	318	318	308	311
Oxygen, wt %	0	0	2.26	2.26	2.7	2.7
Specific gravity	.7270	.7269	.7325	.7329	.7513	.7484
mpg factor	.983	.983	.961	.962	.969	.968
NOX, gm/mi	.6635	.6593	.6892	.6892	.5882	.5914
TAP, mg/mi	56.93	56.92	43.74	43.89	53.12	52.07

Table B.4.
Scenario 2 impact on PADD IV gasoline properties

	CG		RFG		OG	
	B a s e 2 0 0 0	S c e n a r i o 2	B a s e 2 0 0 0	S c e n a r i o 2	B a s e 2 0 0 0	S c e n a r i o 2
Octane, (R+M)/2	87.2	87.1	88.1	88.6	88.7	86.8
RVP, psi	12.3	12.3	12.3	12.3	12.3	12.3
Aromatics, vol %	23.2	23.8	21.3	17.1	18.6	22.1
Benzene, vol %	1.3	1.3	0.6	0.6	0.7	0.7
Olefins, vol %	12.6	13.3	1.3	5.4	19.5	12.3
Sulfur, ppm	256	231	74	227	188	179
T50, °F	184	181	188	192	190	188
T90, °F	330	331	311	307	319	319
Oxygen, wt %	0	0	2.1	2.1	2.7	2.7
Specific gravity	.7230	.7238	.7369	.7201	.7322	.7384
mpg factor	.980	.981	.967	.954	.956	.962
NOX, gm/mi	.6821	.6801	.6169	.6800	.6831	.6572
TAP, mg/mi	51.06	51.87	43.16	40.42	40.90	43.56

Table B.5. Scenario 2 impact on Washington state gasoline properties (shaded cells indicate binding emissions constraints ^a)				
	CG		OG	
	B a s e 2 0 0 0	S c e n a r i o 2	B a s e 2 0 0 0	S c e n a r i o 2
Octane, (R+M)/2	90.1	89.7	88.8	88.7
RVP, psi	13	12.8	12.6	12.8
Aromatics, vol %	27.8	30.4	25.7	24.2
Benzene, vol %	0.4	1.7	1.3	0.9
Olefins, vol %	7.3	6.0	5.8	6.8
Sulfur, ppm	230	280	88	52
T50, °F	186	187	184	183
T90, °F	319	318	321	322
Oxygen, wt %	0	0	2.7	2.7
Specific gravity	.7238	.7288	.7412	.7382
mpg factor	.980	.984	.962	.961
NOX, gm/mi	.6648	.6698	.6002	.5849
TAP, mg/mi	49.66	58.51	48.36	45.91

^aAs suggested by Step 4 of the convergence method in Section 4.2, there can be slight differences between the model-derived emissions value and the actual emissions values. For this reason, it is possible for NOX values to be binding at a single value in the model, while the actual NOX values are slightly different.

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